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AN INVESTIGATION OF VOLCANIC GASES AND DUST (AEROSOLS) IN
THE STRATOSPHERE (NSG 5145): R.W. Decker and S. Self,
Principal Investigators.

Progress Report June 1978 - January 1979

7.9-10.159

CR-158152

During 1978 research continued along two main fronts:

1. Studies of particles sampled from the plumes of
Guatemalan Volcanoes during the NCAR - Dartmouth volcano
plume sampling project in February 1978 (see Rose et al.,
1978; previous progress report on NSG 5145).

2. Research into large historic volcanic deposits
formed by stratosphere-high eruptions from both field and
theoretical aspects (Rampino, Self and Fairbridge, in
preparation).

1. Volcanic Plume Behavior and Particle content:

Movie film taken aboard the NCAR Queenair during the
plume sampling project has been analyzed and the results
written up (Wilson and Self, 1978; Wilson and Self: in
preparation). The final draft of the paper is now being
prepared. The study essentially demonstrates the extremely
fast dilution and cooling of volcanic eruption clouds and
aids understanding of the near-vent behavior of cloud density,
temperature and particle concentration

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GASES AND DUST (AEROSOLS) IN THE
STRATOSPHERE Progress Report, Jun. 1978 -
Jan. 1979 (Dartmouth Coll.) 23 p
HC A02/MF A01

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tribution of Earth Resources Survey
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to the public interest.

Filter and impactor samples were studied during tenure of a two month Visiting Staff Member (V.S.M.) position at Los Alamos Scientific Laboratory (LASL). A report of work completed at LASL and a brief description of techniques used is appended to this report.

Electron microscope and electron microprobe investigations showed larger concentrations of number of particles in the submicronsize range than hitherto expected. However, although number of concentrations are high, the relative mass concentration is small (Fig. 1). Both solid and liquid (acid dropet) type particles were recorded (Fig. 2): the acid appears to be mainly H_2SO_4 (by semiquantitative EDAX analysis). Sulphate salts were commonly found adhered to glass or crystal particles. Results were discussed at the Fall A.G.U. meeting in San Francisco at a symposium entitled "Airborne Sampling of Eruption Clouds of Explosive Volcanoes" (see Cadle and Rose, 1978; Self, 1978). The abstracts of this symposium are attached to this report.

The analytical work on plume content is being written up for publication and a further sampling mission is planned for 1980. Other related studies performed at LASL were geochemical analyses (using the electron microprobe) of the 1978 ash from Fuego volcano. A petrologic comparison will be made with the 1974 ash which was produced by a stratosphere - high eruption column.

2. The 1902 Santa Maria pumice deposit:

Field work by graduate student Stanley Williams on the 1902 Santa Maria deposit in Guatemala and Mexico has been completed. This important deposit was produced by one of the largest eruptions this century. Grain size studies will provide a unique way of estimating the amount of fine dust "missing" from the land deposit. This can be interpreted as material which was widely dispersed, mainly by stratospheric circulation.

Other work:

The Newhall-Self List of Volcanic eruptions is being updated to the end of 1978 and the list will be submitted (to Jour. Geophys. Res.) early this spring for microfiche publication with an attendant paper in the journal (Newhall and Self, in preparation). Work is still in progress on quantification of the Stratospheric Aerosol Index (SAI). Field studies of a 1977 eruption in Alaska, supported by this grant, have now been written up and two papers submitted for publication with co-authors from the University of Alaska Geophysical Institute (Kienle, et al., 1979; Self et al, 1979). General studies of volcanic deposits are continuing (Self and Sparks, 1979 a and b).

Figure Captions

Fig. 1: Semi-quantitative grain size distribution within the Fuego plume, February 1978. $\Delta C/C$ proportion of total mass concentration. Note polymodal distribution of near source column, loss of coarse mode from near source to 14 km downwind and low mass in submicron range. Arrows indicate size ranges sampled by the two types of sample collector.

Fig. 2: Particles in the Fuego and Santiaguito Plumes, Feb. 1978:

- a) coarse particles of glass and feldspar with liquid (dilute acid) coating (Fuego).
- b) large glass particle, with adhering smaller particles, coated by a liquid film. Impactor studies show this to be a dilute acid (Santiaguito).
- c) small particles of plagioclase feldspar (P) and glass (g) on the fluoropore filter (Fuego)
- d) glass and plagioclase fragments in the 0.5 - 5 micron size range attached to a larger glass particle (Fuego).

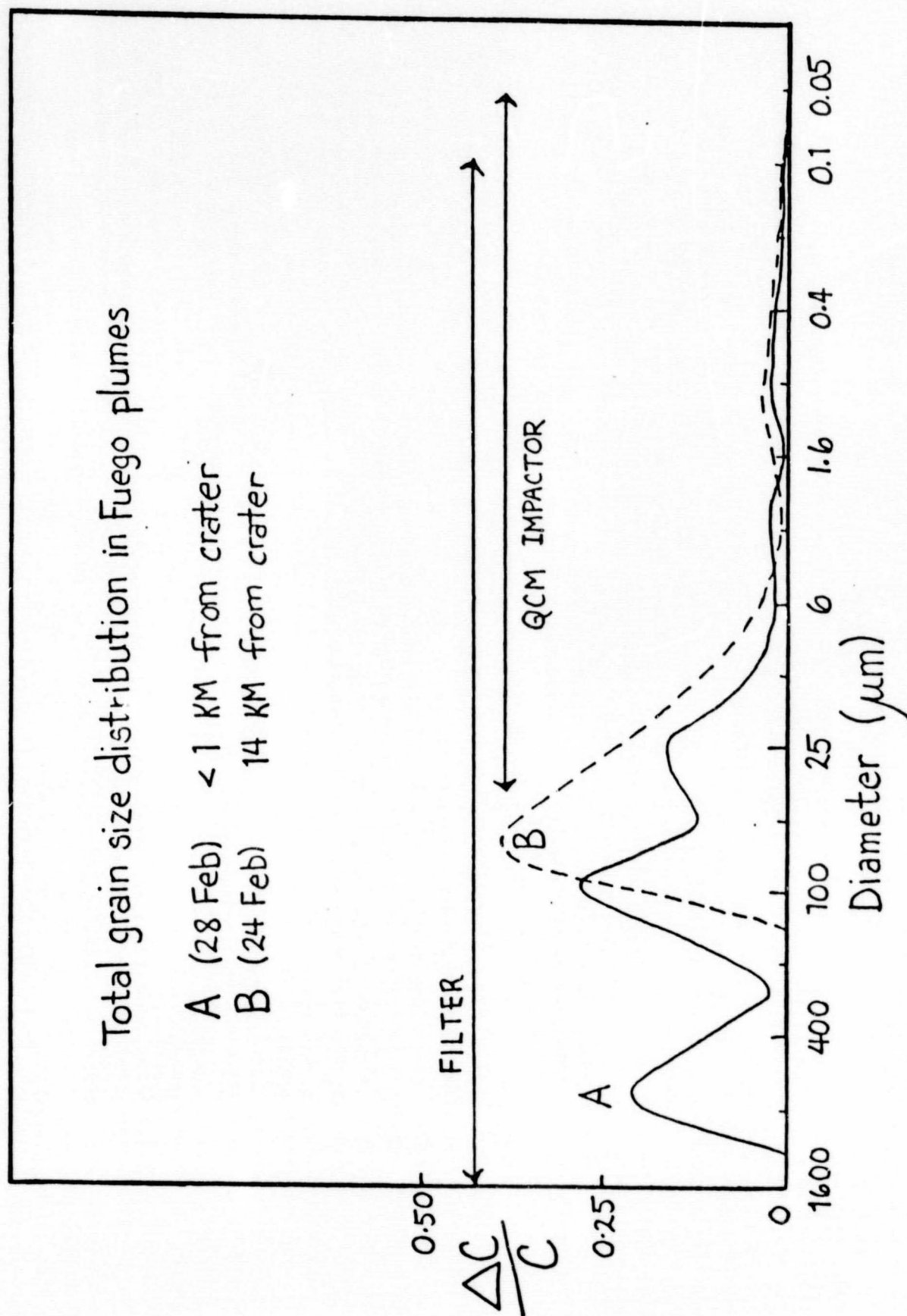


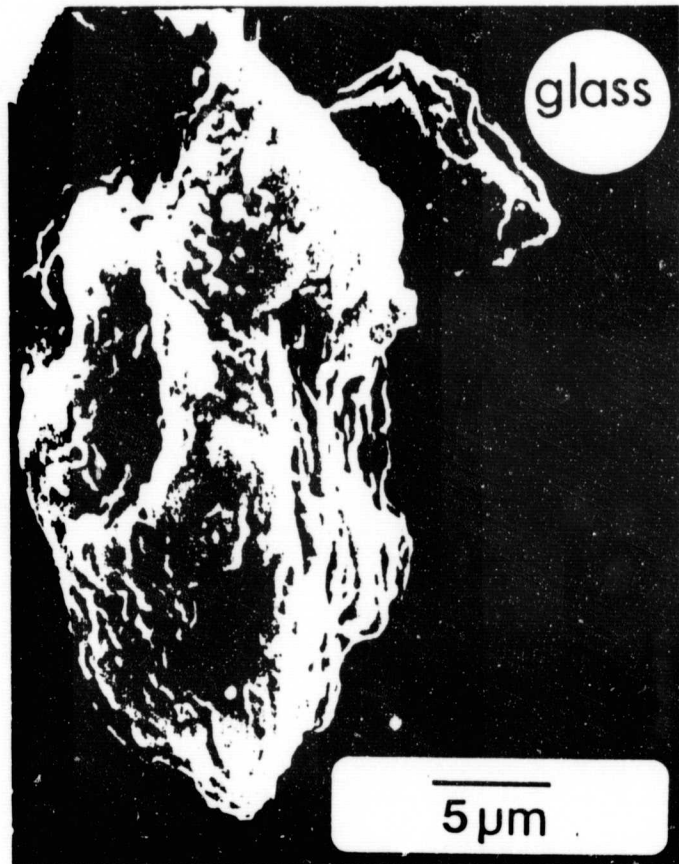
Fig.2



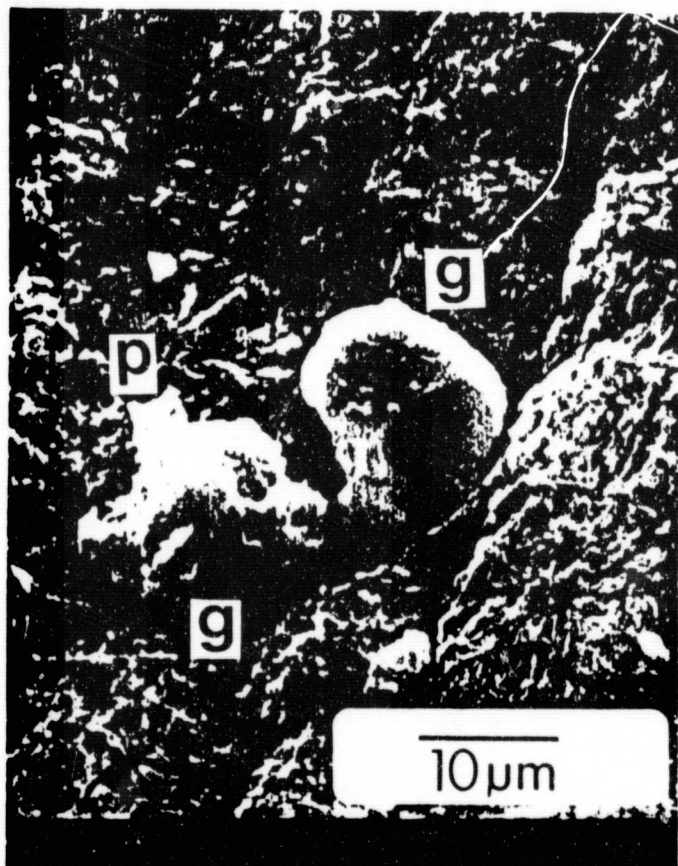
(a)

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(b)



(c)



(d)

Recent publications under NSG 5145:

In Press-

- Self, S., Wilson, L. and Nairn, I.A., 1979, Vulcanian eruption mechanisms, *Nature* (London); (proofs attached to this report).
- Self, S. and Sparks, R.S.J., 1979a, Characteristics of pyroclastic deposits formed by the interaction of silicic magma and water, *Bull. Volcanol.*, 41-3.
- Self, S. and Sparks, R.S.J., 1979b, Discussion of "The oldest marine carbonate ooids reinterpreted as volcanic accretionary lapilli, Onverwacht Group, So. Africa, by D.R. Lowe and G.P. Knauth. *J. Sed. Petrol.* (June).
- Kienle, J., Self, S., Kyle, P.R. and Motyka, R., 1979, Ukinrek Maars, Alaska: I. General Geology and Petrology. *J. Volcanol. Geothermal. Res.*
- Self, S., Huot, J.P. and Kienle, J., 1979, Ukinrek Maars, Alaska: II. Mechanisms and deposits of the 1977 eruption. *J. Volcanol. Geothermal. Res.*

Articles in preparation:

- Wilson, L. and Self, S. Volcanic explosion plumes: density, temperature and particle content estimates from plume motion. To be submitted to *Geophys. Res. Letts.*
- Walker, G.P.L., Self, S. and Frogitt, P. The ground layer of the Taupo Ignimbrite: a striking example of sedimentation from a pyroclastic flow. To be submitted to *Geology*.
- Rampino, M.R., Self, S. and Fairbridge, R.W. Can climate change cause volcanic eruptions? To be submitted to *Science*.
- Wright, J.V., Smith, A.L. and Self, S. A proposed classification of pyroclastic rocks; to be submitted to *Geology*.
- Newhall, C.G. and Self, S. A new volcanic eruption list: applications to the study of volcanic perturbation of global climate; to be submitted to *J. Geophys. Res.*

Abstracts published:

- 1978 Self, S., Kienle, J. and Huot, J-P, Mechanisms and deposits of the 1977 Ukinrek maar-forming eruption, Alaska Peninsular; Geol. Soc. Am. abstracts with programs, 10. p. 489.
- 1978 Rose, W.I., Jr., with S. Self and ten others, 1978 volcanic plume sampling project; Geol. Soc. Am. abstracts with programs, 10. p. 480-481.
- 1978 Self, S., Particle Size Distribution and Morphology of Ash in the Fuego and Santiaguito Plumes. Trans. Am. Geophys. Union (EOS), 59, p. 1222.
- 1978 Wilson, L., Self, S., Volcanic Explosion Plumes: Density, Temperature and Particle Content Estimates from Plume Motions. Trans. Am. Geophys. Union (EOS), 59, p. 1222.

LOS ALAMOS SCIENTIFIC LABORATORY

STEPHEN SELF VSM G-6

Report of Work up until December 31, 1978

Program Number

E-532

Specific Responsibility

1. Increase understanding of pyroclastic rocks in general--has implication for waste storage management.
2. Examination of the first set of samples ever collected systematically from the plume of an active explosive volcano. This gives valuable information of use to proposal recently submitted to DOE by G-6 (G. Heiken), G-8, and CNC-11 to investigate atmospheric contribution of explosive volcanoes.

Accomplishments

1. One part of my study at G-6 consisted of a field investigation of the El Cajete pumice deposits (c. 100,000 years old) in the Valles Caldera. Bad weather has hampered field work but a good start has been made on the stratigraphy, dispersal and eruption sequence of the El Cajete deposits. More field work will be done in April 1979 (under non-LASL funding) and is expected to yield enough data for a paper on these deposits.

Also in collaboration with Grant Heiken (G-6) I have been examining old movie film taken during the 1914 Mt. Lassen eruption. This documents collapse of an eruption column and we expect to be able to produce a short paper on the mechanisms and energetics of collapsing explosive eruption columns (which produce ash flows).

2. A series of ash and aerosol samples collected in February 1978 by Self during a joint NCAR/NASA/ university airborne sampling program at Fuego Volcano, Guatemala were investigated at G-6. The investigation has yielded the first data on size, composition, and concentrations of particulates in eruption

clouds. Also movie film of explosions taken at the same time was previously analysed and the results worked up while at G-6.

Techniques used

1. Field mapping and sample collection for future size and chemical analysis. Movie film analysis, frame by frame, using a microfiche reader.
2. Combined scanning electron microscopy (SEM), energy dispersive semi-quantitative x-ray analysis (EDAX) and microprobe analysis, using instruments in G-6 microprobe laboratory (R. Hagan).

Importance of work and results

1. Field investigations of pyroclastic deposits using quantitative techniques are still rare and the El Cajete deposits are an unusually complex sequence containing examples most of the products of explosive, silicic volcanism. It is expected that the results, when published, will yield an important contribution to understanding of volcanic processes. The movie film studies can be considered as a corrolary to the above because they document the occurrence of eruption column collapse, which is the main cause of the variations seen in the field within the El Cajete deposits.
2. The volcano plume sample studies are the first of their kind and have important impact in understanding the size, composition, and concentration of particles injected into the atmosphere by volcanoes. The main implications of this study are in a better understanding global atmospheric particulate loading by volcanoes and the effects on climate change.

Papers and abstracts published or submitted for publication based on work done at G-6:

- 1978 Wilson, L., Self, S., Volcanic explosion plumes: density, temperature and particle content estimates from plume motion. Submitted to Geophys. Res. Letts.
- 1978 Self, S., Sparks, R.S.J., Discussion of "The oldest marine carbonate ooids reinterpreted as volcanic accretionary lapilli, Onverwacht Group, South Africa, by D.R. Lowe and G.P. Knauth, Submitted to J. Sed. Petrol.
- 1978 Self, S., Particle Size Distribution and Morphology of Ash in the Fuego and Santiaguito Plumes. Trans. Am. Geophys. Union (EOS), 59, p. 1222.
- 1978 Wilson, L., Self, S., Volcanic explosion plumes: density, temperature and particle content estimates from plume motions. Trans. Am. Geophys. Union (EOS), 59, p. 1222.
- 1979 Self, S. and Rose W.I., Jr., Climatic and volcanologic implications of volcano plume sampling studies, Fuego, 1978. To be submitted to J. Volcanol. Geothermal Res.

1978 JOINT
ANNUAL MEETING

OCTOBER 23-26, 1978
TORONTO, ONTARIO,
CANADA

GAC
MAC

GSA

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abstracts with programs



The Geological Association of Canada



The Mineralogical Association of Canada



The Geological Society of America (91st)

with

THE PALEONTOLOGICAL SOCIETY

(70th)

THE MINERALOGICAL SOCIETY OF AMERICA

(59th)

THE SOCIETY OF ECONOMIC GEOLOGISTS

(58th)

SOCIETY OF VERTEBRATE PALEONTOLOGY

(38th)

CUSHMAN FOUNDATION

(29th)

GEOCHEMICAL SOCIETY

(23rd)

NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

(19th)

GEOSCIENCE INFORMATION SOCIETY

(13th)

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IV, and by local contact ion exchange in VI, suggesting presence of pervasive fluid in I-IV, but absence in VI, consistent with features of cataclasis in these zones.

LONG-DISTANCE CHRONOCORRELATION IN THE MIDDLE CAMBRIAN

Robison, R. A., Department of Geology, University of Kansas, Lawrence, Kansas 66045; McGee, J. W., Cities Service Oil Company, Box 300, Tulsa, Oklahoma 74102; Rowell, A. J., Department of Geology, University of Kansas, Lawrence, Kansas 66045; Strickland, D. K., Department of Geology, University of Kansas, Lawrence, Kansas 66045; and White, W. W., III, U.S. Bureau of Land Management, Buffalo Resource Area, Buffalo, Wyoming 82834.

Most Cambrian species are endemic, which creates severe problems in global chronocorrelation. The majority of agnostoid trilobites were probably pelagic and some were cosmopolitan. Two species, *Ptychagnostus gibbus* and *P. atavus*, show widespread stasis throughout their geographical range, but both are separated by morphological gaps from their putative ancestors. Their phylogeny is consistent with a punctuated-equilibrium model of speciation.

The bases of both the *P. gibbus* and *P. atavus* zones have previously been suggested as potential horizons for series boundaries. In many parts of the world the incoming of *P. gibbus* is associated with a marked change in lithology, and in detail, the initial appearance of the species may have been delayed at any given locality. In contrast, *P. atavus* commonly occurs in monofacial open-ocean successions and probably its initial appearance closely followed speciation. In western Utah, a likely area for establishment of a series boundary-stratotype, *P. gibbus* and other trilobites occur with inarticulate brachiopods in the lower part of the Wheeler Shale, which accumulated under relatively deep-water conditions. Without significant change in either lithology or the inarticulate brachiopod assemblage, *P. gibbus* is abruptly replaced by *P. atavus*. Associated changes in polyeroid trilobites, although less extensive, resemble changes at the bases of Late Cambrian biomes, which have been interpreted as adjustments to cooler water. Considering all factors, chronocorrelation based on the first appearance of *P. atavus* is probably as precise as any in the Cambrian.

TRACE ELEMENT GEOCHEMISTRY OF MAFIC AND FELSIC MINETTES, BUELL PARK DIATREME, NAVAJO VOLCANIC FIELD

RODEN, Michael F., Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, and Department of Geological Sciences, University of Texas, Austin, Texas 78712

Potassium-rich minette (3.5-7% K_2O , K_2O/Na_2O) of the Navajo volcanic field containing abundant spinel and rarer garnet ilmenite inclusions were erupted 25-30 million years ago in the central Colorado Plateau. Samples of mafic (49% SiO_2 , 10% MgO) to felsic (60% SiO_2 , 4% MgO) minette from the Buell Park composite kimberlitic breccia-minette diatreme were analyzed for rare earth elements (REE), Pb, Ba, Sc, Cr, and Ta by instrumental neutron activation. Chondrite-normalized REE patterns for all the minettes are similar and highly fractionated ($La = 330-370 \times$ chondrite, $Yb = 5-7 \times$ chondrite). Also, Ba increases slightly through the suite (2100-2350 ppm), while Rb increases by two-fold (100-200 ppm). In contrast, compatible elements decrease significantly from mafic to felsic minette: Cr, 410 to 100 ppm, and Sc, 16 to 9 ppm. A major element model based on whole rock and phenocryst analyses relates mafic to felsic minette by fractionation of diopside, phlogopite, magnetite, and apatite. Apatite fractionation was important in controlling the REE and explains decreasing P_2O_5 and P_2O_5/Ce through the suite. The fractionation of Cr and the "buffering" of the REE are not easily explained by a model in which mafic and felsic minette are derived by different amounts of partial melting of the same source. P_2O_5/Ce ratios (≈ 40) of mafic minettes are lower than that suggested for the source of alkali basalts and nephelinites and are consistent with a source for the minettes enriched in light REE. A garnet ilmenite which initially contained apatite and phlogopite is a possible source.

HYDROTHERMAL TRANSPORT AND DEPOSITION OF URANIUM, AND THE ORIGIN OF VEIN URANIUM DEPOSITS.

ROMBERGER, Samuel B., Department of Geology, Colorado School of Mines, Golden, Colorado 80401.

The stabilities of various aqueous uranium complexes are evaluated at up to 300°C using available thermodynamic data. The distribution of aqueous uranium species are plotted as a function of pH and log oxygen fugacity to determine the complexes responsible for the transport, and the mechanisms for deposition, of uranium in natural hydrothermal systems. When these results are considered along with the hydrothermal alteration and mineral assemblages observed in vein uranium deposits, the following conclusions are reached: 1) Carbonate complexes become less important at elevated temperatures and are not significant in the transport of uranium in hydrothermal systems. 2) In deposits containing fluorine, uranyl fluoride complexes are most important in uranium transport. 3) Chloride complexing is not significant even where chloride activities exceed 1. 4) Under certain conditions phosphate complexing may be important in transporting uranium. 5) The solubility of pitchblende decreases as temperature increases, and therefore cooling is not an adequate mechanism for deposition. 6) Uranium is deposited by an increase in pH or a decrease in activity of complexing anions. These changes may occur as a result of reaction with wall rocks, boiling and loss of volatile components, or mixing with ground

waters. 7) Oxidation of iron in wall rocks may be an effect of, rather than a cause for, uranium precipitation. 8) Pitchblende can precipitate under conditions where pyrite or hematite are stable, or where iron is mobile, resulting in the bleaching of wall rocks.

LARGE-SCALE "GRENVILLE" NAPPE STRUCTURES INVOLVING GRANITIC GNEISSES SOUTHEASTERN ONTARIO AND THE NORTHWEST ADIRONDACK LOWLANDS

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A competent, crumpled, northwest-dipping sheet of granitic gneiss extends from Parishville to Alexandria Bay, N.Y. Apparently isolated leucogneisses (the Canton, Gouverneur, Hyde School, Fish Creek, California, Clark Pond, and other "phacolithic" bodies) result from "egg-carton" structure of the sheet. Contorted, plastically deformed incompetent metasedimentary rocks fill troughs and depressions between domal axial culminations on the granitic sheet.

Structural relationships show the Parishville body, to the east, as the hinge of a major, recumbent, isoclinal nappe, with one limb extending into the Adirondack Highlands. To the west, the granitic gneisses at North Hammond and Alexandria Bay extend the sheet across the St. Lawrence River to include the Rockport granite in Ontario, possibly forming another major fold hinge. The amplitude of these folds approaches 60 miles. They extend a competent granitic stratigraphic unit across the southwestern part of the Grenville Province. The northeast-trending "grain" of Grenville structures represents axial-surface foliations to these nappes.

Granitic rocks of the sheet may represent metasediments or metavolcanics of the Grenville Supergroup which have locally undergone melting and remobilization. Other acidic gneisses beyond the ends of the fold hinges, such as charnockitic gneisses of the Diana and Santa Clara complexes, New York, may be correlative with the Westport, Crow Lake, Gananoque, Lyndhurst, and Perth Road metaplutonic bodies in Ontario and therefore represent rocks derived from anatexis of pre-Grenville basement rocks.

EARLY CENOZOIC PLATE REORGANIZATION

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¹Also University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, Florida, 33149

Synthesis of regional plate movements reveals a major reorganization of global plate motion from Mesozoic to Cenozoic patterns that occurred primarily during the Eocene epoch (53.5 to 37.5 my BP). The reorganization involved reorientation of relative plate motions with large N-S components into large E-W components, continuation of pre-existing E-sea floor spreading, initiation of new E-W spreading, deceleration of spreading rates, and subduction of ophiolites. The reorganization is attributed to increase in resistance imposed on the global plate system by increase in length of E-W trending collisional plate boundaries from 2,500 to 28,500 km during the interval 55 to 40 my BP, forcing the system to reorient along lines of less resistance. The pattern of global plate motion resulting from the reorganization is constrained by the resistance imposed by 19,000 km of collisional plate boundaries.

BIOTURBATE TEXTURES IN MUDDY SEDIMENTS

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LIPPS, J. H., Department of Geology, University of California, Davis, California 95617

The textural properties of muddy sediments are influenced to a large degree by the motility modes and feeding types of their resident biota.

A muddy sediment which contains a dense assemblage of suspension feeding infauna which build tubes will have a bioturbate texture that arises primarily from the activity of its between-the-tubes community. Myriad small sinuous burrows, primarily produced by annelids and crustaceans, will pervade the sediment. Because the tubes constitute a barrier to subsurface locomotion, the large resident skeletonized infauna (bivalves and shrimp) will consist of relatively sessile species that build permanent burrows. The overall effect is to produce a sediment that is cohesive and contains well-defined biogenic structures. Because cemented tubes tend to degrade quickly, paleontologic recognition of a tube-builder association may depend entirely upon the distinctiveness of the suite of sediment traces produced by the coexisting infauna.

By comparison, a less densely populated muddy sediment will have a bioturbate texture that results from deposit feeding and locomotion traces. The active probing of sediment with tentacles, proboscis, and palps will produce a mottled to homogeneous sediment texture. The overall water content of this sediment will be high and deformation of biogenic structures would be expected during preservation.

1978 VOLCANIC ERUPTION CLOUD SMOILING PROJECT

ROSE, W. L., Jr., CADLE, R. D., LAZRUS, A. L., HEIDT, L. E., and D. A. GILLETTE, National Center for Atmospheric Research, Boulder, 80502; HUBERT, B. J., Colorado College, Colorado Springs, CO 80901

STOIFER, R. E., SELF, S. and BRATTON, G., Dartmouth College, Hanover, NH 03755; CHIAN, R. L., Brunswick Corporation, Costa Mesa, CA 92626; WOODS, D. C., NASA Langley Research Center, Hampton, VA 23665; FRIEDMAN, I., ZIELINSKI, R. A. and SMITH, D., U.S. Geological Survey, Denver, CO 80225; WILSON, L., University of Rhode Island, Kingston, RI 02881.

During February and March 1978, a team of scientists and a specially equipped Queen Air Aircraft flew eleven sampling flights over the active volcanoes of Pacaya, Fuego and Santiaguito in Guatemala. Throughout this period each of the volcanoes showed moderate activity and had plumes which could be readily sampled at various altitudes and distances from the active craters.

Equipment on the aircraft included: 1) a treated filter sampler for determination of relative amounts of SO_2 , HCl , HBr , HF , SO_x , particulates and trace elements; 2) a 10-stage Piezoelectric Particle Cascade for particulate size distribution and size sampling of particulates in the range of 25 to 0.05 μm ; 3) evacuated stainless steel canisters for quantitative gas chromatographic measurements of H_2S , COS , CO_2 , CO and SO_2 ; 4) a SO_2 correlation spectrometer for the determination of SO_2 fluxes in the plumes by traversing; 5) an automatic 35 mm multi-speed sequence camera for dynamic photography of erupting plumes; 6) a flow-thru stainless steel gas sampler for H_2 , O and C isotopic measurements of gases; 7) an Inertial Navigation System for ground and wind speed determinations; 8) a gas bubbler sampler for trace element sampling. At abstract time, few results are available.

The project demonstrates clearly the feasibility of planned missions to sample more or less continuous low level emission from the same explosive volcanoes that project material into the stratosphere in short-lived sporadic events.

SNOWBALL MUSCOVITE IN THE CENTRAL SWISS ALPS: AN INTERNAL RECORDER OF TECTONOMETAMORPHISM

Rosenfeld, J. L., Department of Earth & Space Sciences, University of California, Los Angeles, California 90024
Snowball muscovite (SM) occurs with the well-known snowball garnet (SG) in north-dipping, staurolite-zone, Liassic calcareous schists in the isoclinal Piura Syncline separating the Gotthard and Lucomagno massifs. Its lower symmetry causes SM to reveal petrogenetic features beyond those shown by SG. Some muscovite recrystallized around new nuclei of scattered orientation while other coexisting muscovite reacted to form snowball biotite. Rotation of SM and their simultaneous, orientation-dependent, anisotropic growth-rate caused changes in cross-sectional shapes normal to their rotational axes from relatively euhedral $\{001\}$ -foliation (S) to elongate $\parallel [001] \parallel [001] \parallel [S]$. Low angular velocity in the latter state kept S parallel to the synclinal axial surface (cf. D. Willis). Garnet pseudomorphs of muscovite, including earlier SM, demonstrate muscovite translocation by cation exchange, probably along intergranular boundaries influenced by differences in surface energy and changing phase equilibrium. SM, SG, and other snowball minerals show rotational sense that is invariant with position in the syncline. Their south-side-up sense indicates growth during Chadwick's tectonic Phase V after folding of the Piura Syncline. That shear, with elongation parallel to the dip (e.g. boudinage of zoisite during growth), probably derived from Oligocene southward tilting of the bordering, more competent massifs, caused by southward slumping of material at a higher crustal level. That movement also accounts for refolding of nappe-related isoclinal folds in the Triassic dolomite at nearby Passo Campolungo.

ECOLOGY OF LARGER, SHALLOW-WATER TROPICAL FORAMINIFERA

ROSS, Charles A., Department of Geology, Western Washington University, Bellingham, Washington 98225

Modern coral reefs are inhabited by a great abundance and diversity of species of Foraminifera. On exposed reef flats and exposed shallow intra-reef basins species of Calcarinidae and Amphisteginidae dominate the *Thalassia* (turtle grass) blades and may form the substrate of the basins, the upper surfaces of which are bound together by foraminiferal pseudopods. Although most of these species are relatively small, the families Soritidae and Alveolinidae have representatives that reach shell volumes greater than 100 mm. The soritid *Marginothammina vertebralis* occurs abundantly in a number of different reef environments, including clinging to *Thalassia* blades in 1 to 2 m deep protected lagoons. *M. vertebralis* and other larger foraminifera start to appear consistently on substrates composed of smaller foraminifera in deeper intra-reef basins 8 to 25 m deep on exposed reefs, and inter-reef channels about 25 m deep. Growth rate decreases but the final size necessary to reach reproductive maturity increases below a depth of 10 m, so that the largest specimens are from the deeper locations.

The shallow depth limits in the distribution of large reef-dwelling foraminifera are related to exposure to waves and currents that are of sufficient strength to displace the foraminifera and redeposit them in deeper water. The lower depth limits, at least for the soritids, are related to the depth at which their photosynthetic zooxanthellae partners are no longer effective symbionts.

ASBESTOS HEALTH RISKS TO THE MINING COMMUNITIES OF NORTH AMERICA

ROSS, Malcolm, U.S. Geological Survey, 959 National Center, Reston, Virginia 22092

Mesothelioma, a cancer of the pleura and peritoneum, occurs, with few exceptions, only in asbestos "trades" workers (ship insulation, textiles, construction, etc.) and in South African crocidolite miners. Lung cancer is seldom found in non-smoking asbestos "trades" workers. The percent mortality for lung cancer and mesothelioma is plotted for 11 groups of "trades" workers. Regression analysis of these data shows a linear relationship between lung cancer and mesothelioma incidence; 79% of the variance (r^2) of lung cancer is accounted for by mesothelioma. A large part of the remaining 21% variance can be accounted for by intergroup differences in smoking statistics. Cancer mortalities are also plotted for adult male populations of 5 nations and for 6 "asbestos" mining/factory populations not exposed to crocidolite. The very low incidence of mesothelioma in these groups shows that they do not have the cancer risk experienced by those in the "trades"; their lung cancer incidence is generally accounted for by smoking habits alone. Cancer risk to those in the "trades" is attributed to exposure to both smoke and crocidolite. There is no evidence that the mineral dust levels presently maintained in responsibly operated mines of North America cause increased incidence of lung cancer or mesothelioma, including those mines that process rock containing the commercial forms of asbestos: anthophyllite, tremolite, actinolite, cummingtonite, grunerite, and chrysotile.



THE DFE PROGRAM IN ENVIRONMENTAL IMPACT OF THE DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE IN GEOLOGICAL FORMATIONS

Rothschild, H. C. and Barraud, C., Nuclear Programs Division, Department of Fisheries & Environment, Ottawa, Ontario, KIA 1C8.
Fisheries & Environment Canada's interest in the problem of disposal of high level nuclear wastes in geologic formations involves the participation of two services: Environmental Management Services (EMS) and Environmental Protection Services (EPS). EMS is supporting applied research in hydrogeology and groundwater geochemistry for determining the transport/retardation mechanisms of radionuclides in the sub-surface environment. The EPS involvement consists of preparing a document providing recommendations for long-term protection of our environment with respect to disposal of high level radioactive waste. This document will cover two main topics:

- (a) evaluation of long-term physical and chemical stability of the different rock types considered to be potentially suitable as high-level waste disposal media.
- (b) evaluation of the efficiency of the geologic barrier for long-term containment of long-lived radionuclides.

Conclusions drawn from this document will provide a base for recommending improvement of solidification techniques to produce synthetic matrices with long-term physical and chemical stability and with lower leaching rates than the present day glass or ceramic matrices.

DEVELOPMENTAL CYCLE AND SYMBIOSIS OF THE RECENT HETEROSTEGINA DEPRESSA, AND THEIR IMPLICATIONS FOR THE OCCURRENCE OF THE MICROSOPHERIC GENERATION

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The developmental cycle of *Heterostegina depressa* has been investigated in laboratory cultures and in specimens from natural habitats in Hawaii. As in other foraminiferal species, alternation of generations also exists. However, megaspheric specimens (gamont, A-form) are much more abundant than microspheric specimens (agamont, B-form). This seems to be true for all larger foraminifera (Recent and fossil). The reason for this is that multiple fission is the main mode of reproduction of the megaspheric generation. Gamete formation, which leads to the microspheric generation, is greatly reduced. The symbiotic diatoms which are essential for the metabolism of this foraminifer are easily transferred over many megaspheric generations during multiple fission. Gametes, which are rarely formed by megaspheric individuals, do not transfer symbionts to the microspheric generation. Consequently, the microspheric generation has to engulf free living diatoms during its early individual development and transform them into symbionts. The transformation process makes the establishment of symbiosis more difficult in the microspheric generation. Such difficulties along with the scarcity of gamete formation may account for the small number of microspheric specimens found in natural habitats and for their special depth distribution. Microspheric specimens occur to a depth of 100 m with the highest frequency in the deeper regions of this range.

THE PAST AS A KEY TO THE PRESENT: PLANKTONIC FORAMINIFERA AND STEREOPODS IN SOUTH CHINA AND JAVA SEA SEDIMENTS

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Vulcanian eruption mechanisms

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Macmillan — Nature Paper 326/2 — Wilson — ST

Application of a newly developed theory to volcanological observations of explosive eruptions shows that previous estimates of pre-explosion gas pressures may be overestimated by an order of magnitude.

The andesite stratovolcano Ngauruhoe, in North Island New Zealand, erupted explosively during the afternoon of 19 February 1975. The eruption was closely observed and filmed. There were two main phases. A 1.5-h gas streaming phase¹ produced an 11–13 km high eruption column which was continually fed by a large number of closely spaced explosions. This phase was followed by a series of discrete cannon-like explosions at 15 to 50 min intervals over a period of 5 h (ref. 2). The latter type of activity is common on many andesite and basaltic andesite volcanoes, for example Avama³ and Arceno⁴, and is referred to as vulcanian type activity⁵.

Vulcanian explosions have been studied from several recent eruptions⁶ and display common characteristics: the rock mass ejected per explosion is usually 10³ to 10⁴ tonnes (ref. 3, 6) and often contains a high proportion (≥50%) of nonjuvenile material, during active periods, intervals between explosions vary from <1 min (Anak Krakatau⁷) to about 1 day (Avama³, Sakurazima⁸), pyroclastic avalanches (*nuées ardentes*) are often produced^{9, 10, 11}.

The February 1975 eruption of Ngauruhoe was recently described¹. Here we use newly developed theory to analyse the largest of the cannon-like explosions (at 18.10 h on February 19) and discuss the mechanisms of vulcanian explosions. McBirney¹² recently reviewed controls on explosive andesite eruptions and criticised the use of the Bernoulli equation to derive pre-explosion pressures. However, use of the 'gun barrel' equation, recommended by McBirney, is also open to criticism. This article corrects some earlier computations^{13, 14} of pre-explosion pressures at Ngauruhoe and demonstrates that gas pressures required to generate vulcanian explosions are probably much lower than previously thought.

Direct observations of discrete vulcanian explosions

The best documented discrete explosion at 18.10 h consisted of the expulsion of a cloud of gas containing fragments with a wide range of sizes. The initial velocity was supersonic, resulting in a shock wave¹. The position and extent of the cloud was recorded on a series of photographs, timed with sufficient accuracy for estimates to be made of the average velocity between each pair of photographs. Figure 1 shows the resulting variation of velocity with height; an estimate of errors has been included.

It is known that the velocity of a cloud of material ejected into the atmosphere at high speed must decrease approximately exponentially with height¹⁵ and so a minimum initial velocity can be obtained by fitting a straight line to the data in Fig. 1. Clearly the initial velocity was at least 400 m s⁻¹ and may have been as high as 500 m s⁻¹. The fact that a shock wave accompanied the explosion demonstrates that the velocity was greater than about 300 m s⁻¹. A best estimate of 400 m s⁻¹ is adopted, as this value was also obtained from the measured ranges of 1 m diameter blocks ejected by the same explosion¹.

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Theory of vulcanian explosions

Discrete, intermittent explosions must be the result of the sudden release of pressure in a gas by the failure of some form of retaining medium. In the vulcanian case the gas may be magmatic or meteoric. It seems improbable that a layer of unconsolidated clasts at the top of the conduit can substantially retain the build-up of an appreciable gas pressure. We assume, therefore, that magma is always involved in such events. New magma rises in a conduit after a previous explosion and cools at its upper surface, forming a cap.

The compressional strength of dolomite is known to remain nearly constant¹⁶ with temperature up to 950 °C, in view of the lack of evidence to the contrary, we assume that tensile strengths of rocks, commonly quoted to be of the order of 10% of compressional strengths, also remain constant up to this temperature. Tensile strengths (at low pressures) of 100–200 bar are deduced for rocks of andesitic type from the limited data available^{17, 18}. To obtain an estimate of the thickness of crust sufficiently cool to provide a strength of this order, standard treatments on heat flow can be used¹⁹. Cooling from magmatic temperature (say 1,000 °C) during the 50 min interval before the 18.10 h explosion could have produced a layer, cooler than 950 °C, which was up to 15 cm thick; the distance a thermal wave can travel in rock in this time. Clearly, cool fragments of rock debris smaller than 30 cm in diameter would be efficient heat sinks on this time scale. Indeed, the addition of 10% by weight of such debris, derived from the conduit walls or the fall-back in the vent area from earlier explosions, would cool a layer of any desired thickness to 950 °C.

Many attempts have been made to relate the ejection velocity of fragments from volcanic explosions, particularly those of vulcanian type, to the initial pressure of compressed gas driving the explosion^{20–22, 23, 24}. All of these treatments are essentially based on a modified form of the Bernoulli equation. We are not satisfied that this equation adequately represents the conditions in any actual volcanic explosion.

The simplest treatment of an explosion driven by expanding gas is one in which it is assumed that complete decompression to atmospheric pressure occurs, and that all of the internal energy released by the expansion is used to accelerate the explosion products, both released gas and clasts, to the same velocity. The energy equation²⁵ is then

$$-\int \frac{dP}{\rho} - \int g \, dh = \frac{1}{2} u^2 \quad (1)$$

in which ρ is the bulk density of the explosion products, P is the pressure, g is the acceleration due to gravity, h is the vertical coordinate and u the velocity. ρ must be defined in terms of n , the weight fraction of released gas in the exploding mixture, σ , the gas density, and σ_c , the clast density:

$$\frac{1}{\rho} = \frac{n}{\sigma} + \frac{1-n}{\sigma_c} \quad (2)$$

σ is in turn dictated by the temperature, pressure and composition of the gas; in the present circumstances it is adequate to assume that the perfect gas law applies. It is necessary, before integrating equation (1), to decide whether the gas expansion will be more nearly isothermal or adiabatic; the deciding factor is the efficiency with which heat can be transferred from clasts to gas and depends on the clast size distribution²⁶. In the case of Stromboli explosions, in which the time scale is very short, an adiabatic approximation is valid²⁷. For vulcanian explosions, the best solution probably lies between the isothermal and adiabatic cases. The results of integrating (1) using (2) are

$$nRT \ln(P_i/P_f) + \frac{(1-n)}{\sigma_c} (P_i - P_f) = g \Delta h + \frac{1}{2} u^2 \quad (3)$$

in the isothermal case and, in the adiabatic case

$$nRT \left[\frac{\gamma}{(\gamma-1)} \left(1 - \left(\frac{P_f}{P_i} \right)^{\frac{(\gamma-1)}{\gamma}} \right) \right] + \frac{(1-n)}{\sigma_c} (P_i - P_f) = g \Delta h + \frac{1}{2} u^2 \quad (4)$$

where P_i is the initial pressure driving the explosion, P_f is the final pressure, assumed equal to atmospheric, Δh is the vertical distance over which the gas decompression occurs, γ is the ratio of the specific heats of the gas, R is the gas constant and u is the final velocity. If numerical values are inserted, it is generally found that the term $g \Delta h$ can be neglected for explosions in which the expansion of gas occurs over a vertical distance of less than a few hundred metres.

The modified version of the Bernoulli equation is usually written

$$P_1 - P_2 = \frac{1}{2} \rho v^2 \quad (5)$$

in terms of the variables already defined. There has been some discussion¹¹ as to what density should appear in this equation ρ , (as written here) or ρ_0 . Comparison of equations (5) and (3) reveals the essential problem with the modified Bernoulli equation: it only approximates the correct expression if n is sufficiently small (and if Δh is also small). The values of n encountered in real volcanic explosions (say 0.1 to 30 weight per cent of plume, vulcanian and strombolian events are included) are always too large for this approximation to be true.

We have argued above that the build up of pressure beneath a restraining cap may be the source of vulcanian explosions. In such a case the mixing of gas and clasts from the disrupted cap and the surrounding rocks may not be great in the early part of the motion, a physical model based on the motion of a solid block of coherent (or shattered) rock overlying a gas body of similar cross sectional area may be more applicable. If the vertical extent of the cap is L and its density is ρ_0 , and if the gas body beneath the cap has vertical extent X , initial temperature T_0 , pressure P_0 and gas constant R , then simple geometry shows that

$$\frac{X}{L} = \left(\frac{n}{1-n} \right) \left(\frac{\rho_0 R T_0}{P_0} \right) \quad (6)$$

so that the solutions may again be expressed in terms of n , the gas weight fraction in the explosion products. The equation of motion for the cap in the vertical h direction is

$$P - P_0 = L \rho_0 g - L \rho_0 g - \frac{1}{2} C_D \rho_0 v^2 \quad (7)$$

where P is the general value of the pressure during the expansion. P is given by

$$P = P_0 \left(\frac{X}{X+h} \right)^{\frac{1}{1-n}} \quad (8)$$

initially, since the expansion is adiabatic until some small clasts begin to mix with and supply heat to, the gas. The final term in equation (7) represents atmospheric drag acting on the rising cap. C_D is a drag coefficient with value close to unity and ρ_0 is the atmospheric density. Equation (8) is readily integrated numerically using equations (6) and (8) to yield the maximum velocity, v_m , of the products during the explosion process. The results of such calculations, and also of the use of the simpler equations (3) and (4), are summarized in Fig. 2, in which v_m is shown as a function of P for a range of values of n in each case.

The fact that at least 60-65 wt % of the fragments ejected during the 18 10 h explosion were smaller than 10 mm (ref. 1) and able, therefore, to maintain thermal equilibrium with the gas during most of the explosion¹², implies that the velocities corresponding to equation (3) (isothermal case) may be more appropriate for vulcanian explosions than those derived from equation (4), the solutions to equation (7) certainly represent the lowest possible velocity that corresponds to any particular pair of values of n and P , as they give the greatest weight to energy losses. The speeds given by equation (4) are very close to those from equation (3) at low pressures and fall to about 70% of the equation (3) speeds as the pressure approaches 1,000 bar. The n and P values given below are means of equations (3) and (7) biased towards equation (3) on the basis of this argument.

The following combinations of initial gas pressure and released gas wt % are implied by the observed maximum velocity of 400 m s⁻¹ for $n = 10\%$, $P_0 = 2-5$ bar, for $n = 10\%$, $P_0 = 10-30$ bar, for $n = 5\%$, $P_0 = 40-100$ bar, for $n = 3\%$, $P_0 = 100-300$ bar. We argued above that the likely range of values of tensile strength of andesite at sub-solidus temperatures is 100-200 bar (refs 14, 15). Then the above permutations of pressure and gas content would imply that the explosion products of the 18 10 h event contained 2-5 wt % water. It was estimated¹ that equal proportions of juvenile and nonjuvenile material were expelled in the explosion, and so if it is assumed that all of the water were juvenile, 4 to 10 wt % would be required in the magma. The lower end of this range is comparable to the measured primary water contents^{11,13} of andesite magmas, but it is probably implied that some meteoric water was also involved.

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Magma volume and conduit shape considerations

The total volume of rock expelled in the 18 10 h explosion and four other similar outbursts on the same day was about 5×10^7 m³ dense rock, approximately half of which was juvenile. We may assume that juvenile material was re-emplaced in the upper parts of the volcano between explosions, so that a total of about 2.5×10^7 m³ of pre-existing cone material was excavated.

This volume cannot have been removed from a localized region near the vent because we know that there were no significant changes in the geometry of this region during the explosive activity, if a vertical length of say 500 m were involved, the excavated cylinder needed to provide both the juvenile and nonjuvenile debris for all five major explosions would have had a diameter of 32 m. Figure 3 shows the situation envisaged: a long cylindrical conduit about 20 m in diameter containing magma, cooled at the surface and chilled at its contact with the cone material, contains clasts which have fallen into the conduit from earlier activity. Water in these clasts and in the cone material immediately surrounding the magma is heated to near magmatic temperatures and, together with exsolved juvenile magmatic water, drives the explosion when the cap over the vent fails. It is not possible to estimate accurately the relative contributions from magmatic and juvenile water. The 18 10 h explosion may have removed a rock layer some 5 m thick from the cone, it is likely that the observed mass. Only a small fraction of this rock and its pore water could have been heated by conduction in the 50 mm before the explosion, although water and steam in interconnected fissures may have been heated by convection. If all the available water in the wall rock layer were involved in the explosion, a water content of 2-3% in the rock would be consistent with the expected water contribution from the magma as noted above.

In the above treatment we have not found it necessary to invoke the rapid mixing of juvenile material with ground-water that might lead to flash boiling¹⁴. This mechanism has been proposed as a means of creating pressures of the order of 1-5 kbar, similar to the pressures deduced for high velocity explosions¹⁵ by applying the Bernoulli equation. Our analysis does not require such high pressures, indeed, we doubt that they are ever required.

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Eruption column behaviour

The rise height, H , of the convective plume from the 18 10 h explosion can be computed from a formula for convective rise from an instantaneous source and compared with the observed height, H_0 , in metres, is given¹⁶ by

$$H = 1.8 Q^{1/3} \quad (9)$$

where Q is the released heat energy in Joules. The 18 10 h event emitted 2×10^{10} kg of rock, of which about half was juvenile (that is, hot and able to contribute to driving convection). However, about half of the material injected into the plume was lost almost immediately (after 12-15 s) by the partial collapse of the column to form pyroclastic avalanches¹. Thus, the heat available to drive convection is estimated to have been a maximum of 4×10^{10} J, leading to a predicted column height, H , of 4,700 m. The observed value¹ was at least 4,000 m, the discrepancy implying an efficiency of heat utilization of about 50%.

This may be compared to values much closer to 100% found for sustained plumes produced by other eruptions¹⁸ and also to the value found for a sustained plume at Ngauruhoe. During part of the gas streaming eruptive phase, lasting from 13.25 to 13.45 h, prior to the series of discrete explosions, a 12 km high convecting column existed¹⁹ over Ngauruhoe. The equivalent of equation (9) for continuous column convection is

$$A = 8.2Q^{1/4} \quad (10)$$

where A is the column height in metres as before and Q is the rate of release of heat energy in Watts. A 12 km column height implies a mass eruption rate of $3.2 \times 10^6 \text{ kg s}^{-1}$ (ref. 25). The measured volume¹ erupted in this cloud was $1.6 \times 10^9 \text{ m}^3$ dense rock which, averaged over 20 min and using the density of andesite equal to $2,550 \text{ kg m}^{-3}$, corresponds to $3.4 \times 10^6 \text{ kg s}^{-1}$, in good agreement with the above value, suggesting that the efficiency of conversion of heat to work was close to 100% in this case.

Vulcanian explosions are very common at the many active andesitic strato-volcanoes clustered along subducting plate margins. Some of these eruptions are more violent than those described from Ngauruhoe²⁶. However, previous estimates of pre explosion over pressures have generally been too large, and this article demonstrates that relatively small pressures are needed to produce the observed behaviour during this type of eruption. Basaltic andesite magmas have water contents comparable to those deduced for the explosions²⁷, and the involvement of groundwater is possibly a significant feature of the events, but not an essential feature as proposed by Schminke²⁸. It is not necessary to invoke violent mixing of juvenile material and groundwater to explain the explosions. Eruption cloud heights can be related to the rate of release of juvenile material during steady gas streaming activity, and to the amount of released material in discrete explosions, using the formulae found to apply to larger scale eruptions²⁹.

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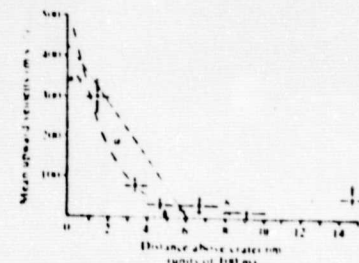
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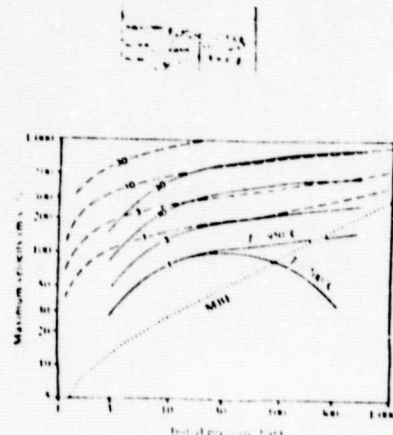
Fig. 1 The deceleration of 18.10 h plume from analysis of still photographs. Errors shown as bars. Straight line fitted between maximum and minimum values. Curved line approximates exponential deceleration. A is speed of sound in air for reference. The steep portion of curve (a) represents deceleration in gas thrust phase; the flat portion (b) represents slow, stable velocity condition while mixing with air and column collapse takes place. c is a slight increase in velocity at beginning of convective thrust phase. The downwards pointing arrow indicates onset of column collapse.

Fig. 2 Maximum velocity of explosion products as a function of initial pressure driving the gas expansion for various types of volcanic explosions. The dotted line MHI is the modified Bernoulli equation (13). The dashed lines are calculations using equation (14) and are labelled by the wt % gas taken to be entrained and used in the calculations. For these curves perfectly elastic contact between gas and clasts is assumed. The solid curves, also labelled by wt % gas in the exploding mixture, represent solutions to equation (15) for the gas cools adiabatically during its expansion from an initial temperature of 1,220 K, in the case of the curve for 1% gas the effect of reducing the initial temperature by 250 degrees is shown. The dashed and continuous curve for each gas content bracket the upper and lower limits of velocity for a given driving pressure in volcanic explosions. When the ejecta are predominantly less than 10 mm in diameter, velocity values correspond more closely to the dashed curves.

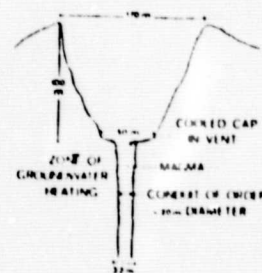
Fig. 3 Schematic of proposed construction through crater region of Ngauruhoe before the 18.10 h explosion.



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NGAUC/0326-2 Wilson 4.0%



NGAUC/0326-3 Wilson 2.1%

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reacted with seawater at an initial solution to rock mass ratio of 2.4 in Dickinson gold-cell equipment of 120 ml capacity. The $\Delta^{18}O$ of the seawater was adjusted to ± 0.02 by addition of $H_2^{18}O$ -enriched water. The equipment rocks 60° above and below horizontal during reaction, to better mix the solids with liquid. Three to six ml aliquots of solution are taken at regular intervals for isotopic and chemical analysis without interrupting the reaction. Rapid isotopic exchange took place. The $\Delta^{18}O$ value of solution quickly dropped and became stable at ± 0.52 in 30 hours. The $\Delta^{18}O$ value of the solid after 10 hrs was calculated to be $\pm 0.50 \pm 0.52$, about 0.52 above the $\Delta^{18}O$ value of solution, a fractionation similar to that expected for K-feldspar and water at 300°C. The solution composition also changed rapidly during the first 30 hrs to a SiO_2 -rich, Na-K-Cl solution with low Mg (3.8 ppm) and Ca (270), closely approximating results previously reported by Dickinson. To test the roles of Mg in the reaction, after 66 hrs 2 ml of saturated $MgCl_2$ was injected, causing drops in pH, from 3.8 to 2.5, and in SiO_2 , from 2000 to 1700 ppm. The pH and SiO_2 slowly returned to steady values of 3.4 and 2250 ppm, resp. After 600 hrs, Mg had fallen to 45 ppm and was still decreasing. Some Mg silicate quickly formed at the time of injection, accompanied by release of H^+ ion, and Mg and H^+ are being slowly consumed by sluggish reaction with silicates. The subsequent lower pH and higher SiO_2 suggests that pH plays an important role in setting the metastably high concentrations of SiO_2 commonly observed in rock-solution reactions.

EXPERIMENTAL ALTERATION OF RHYOLITE GLASS AT 300°C, IMPLICATION FOR SILICATE MINERAL ZONING IN THE McDermitt Mercury Deposit, Nevada

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(Sponsor: J. G. Liou)

Rhyolite glass from the McDermitt caldera complex was reacted at 300°C with distilled water and 2% and 10% NaCl solutions at a water-to-rock ratio of 3:1. Solid phases were identified by optical, X-ray, and SEM methods. In the distilled water the rhyolite glass was completely altered to K-feldspar, albite, cristobalite, and mordenite. The K-feldspar as determined by X-ray is nonanomalous high xanidine with 85 percent Or, the cristobalite is completely ordered with a d(101) of 4.05. In the NaCl experiments reactions were incomplete; the rhyolite glass was only partially altered to zeolites. Coating of the glass shards by the zeolites retarded further interaction of the glass with the fluid. In the 10% NaCl experiment the predominant zeolite was a K zeolite similar in habit to clinoptilolite but having an X-ray pattern similar to ferrierite. Other zeolites present in small quantity included analcime and mordenite. In the 2% NaCl experiments the K zeolite again predominated with small quantities of mordenite being present. Analyses were not made.

The alteration assemblages found in the experiments are similar to those observed at the McDermitt mercury deposit where K-feldspar and cristobalite occur in the ore zone and clinoptilolite and mordenite predominate outside the ore zone. The experimental results suggest that the observed mineral zoning could be explained equally well by differences in solution composition as by differences in temperature.

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REACTION OF RHYOLITE WITH H_2O AND $NaCl-H_2O$ AT 300°C AND 500 BARS

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Rhyolite glass (-150 mesh), in 3/1 initial solution to rock-weight ratio, was reacted at 300°C and 500 bars for about 900 hours with NaCl solutions in gold cell equipment. Internally

filtered solutions, taken at regular intervals, were analysed. Near steady state solution compositions were obtained within 100 hours.

Solution compositions (ppm) after 600 hours

Run	NaCl	SiO_2	K	Ca	As	Ag	B
1	0	1800	70	0	<1	<0.01	0.1
2	2	1180	1840	7.8	2.2	<0.01	4.2
3	10	1300	5100	180	5.0	-0.038	<10

Au	Fe	Mg	Mn	Pb	Sb	Tl	pH
<0.006	3.1	<1	<2	<0.06	<11	<0.2	8.0
<0.006	3	<1.3	<1	<0.3	<32	<0.25	6.0
<0.058	2.0	<7.5	11.0	3.8	<9	<50	5.4

Solution compositions showed sharp changes initially, with lows in pH and high levels of many components, 2 to 5% their steady state values, during the first 100 hours. Run 1 solutions dissolved more than 9000 ppm SiO_2 , which dropped sharply to 2000 ppm at about 150 hours, presumably signalling a nucleation event. Minima in pH values coincided with maxima in concentrations. Steady pH values and SiO_2 concentrations were successively lower for higher NaCl concentrations. In contrast to the opposite trends shown by K, Ca and most minor elements.

The rhyolite glass reacted rapidly with the solutions. The heavy elements extracted from the rock are those found in many epithermal ore deposits (As, Ag, Au, Pb, Sb, and Tl), evaporitic lake deposits (B), and hot spring waters (Mn, Fe). Solutions of Run 1 have compositions similar to dilute geothermal fluids in rhyolitic host rocks.

V 70

THE INTERACTION OF NaCl SOLUTION AND SEAWATER WITH ANDESITE, 200°-400°C, 500-1000 BARS

J. G. Liou
F. W. Dickinson (both at: Geology Department, Stanford University, Stanford, CA 94305)

Some geothermal systems of Japan in andesite have meteoric water or seawater, or mixtures, with modified compositions. Studies are going on in the Stanford Hydrothermal Laboratory of interaction of H₂O, 1000 ppm NaCl solutions and seawater with powdered (-200 mesh) andesite (JA-1 standard; plagioclase, quartz, pyroxene, glass) 200-400°C, 500 and 1000 bars, at 10/1 and 50/1 sol. to rock mass ratios (S/R), 750 to 1500 hrs, in gold cell equipment. Table shows steady state solution values (ppm). All solutions initially dropped in pH and later rose. Acid release accompanied silicate mineral production. SiO_2 rapidly increased above quartz solubility, and was higher at lower pH's; H^+ may interact with SiO_2 . K grew in steadily at a decreasing rate. Ca, Mg and Fe showed the greatest variability with solution type and T. Run 3 at 50/1 S/R was lower in pH, K and Ca compared to Run 2. Fe, low in NaCl solutions, was high in seawater; Run 7 with 520 ppm at 24 hrs, dropped sharply to 227 ppm by 166 hrs, reflecting nucleation of a Fe-mineral. Geothermal fluids in andesitic rocks should adjust in manners similar to the experiments.

Solution composition in ppm. Pressures: 500 bars; Runs 5, 7, 1000 bars. Times: 720 hrs., except Run 1, 360 hrs; Fe, Run 7, 166 hrs.

Run	T°C	Sol.	pH	SiO_2	K	Na	Ca	Mg	Fe
1	300	H ₂ O	6.2	1180	8	12	6.6	5.6	19.0
2	200	NaCl	7.1	630	21	412	5	--	-0.5
3	200	NaCl	6.5	640	12	--	3	0	-0.5
4	300	NaCl	6.5	1200	74	170	5	24	-0.5
5	400	NaCl	6.2	1550	155	390	--	--	-0.5
6	300	SW	3.1	2050	830	11300	250	265	250
7	400	SW	4.2	1760	1030	11200	395	3	227

V 71

REACTION OF CARBONATE ROCK WITH 1% NaCl SOLUTION, 300°C, 1000 BARS

A. S. Radtke, (U.S. Geological Survey, Menlo Park, CA 94025)
F. W. Dickinson, (Geology Dept., Stanford Univ., CA 94305)
D. R. Jamieson, (Geology Dept., Univ. Minnesota, Minneapolis, MN, 55455)

(Sponsor: J. G. Liou)

Powdered silty carbonate rock (-200 mesh), (dolomite, calcite, illite, quartz) was reacted with 1% NaCl at 300°C, 1000 bars, in rocked gold-cell equipment, at 1/1 and 10/1 initial solution to rock mass ratios, for 1000 hrs. Illite reacted with dolomite, SiO_2 and H_2O to form montmorillonite, calcite and CO_2 .

Internally filtered solutions, sampled at regular intervals, were analysed for major and minor elements, H_2S , CO_2 , and pH (See Table). Reactions were exothermic and rapid. Some solution components (As, S, Hg, Tl, Fe, Al, Pb) showed strong maxima by 50 hrs., others showed broad maxima (As, K, Ca) or steadily increased (SiO_2 , K, Ca, Mg, R, Li). Fast achieved steady values within 100 hrs. Some dolomite and illite remained in the 1/1 run. All dolomite decomposed in the 10/1 run. pH of 10/1 at experimental conditions was at least one unit higher than pH of 1/1 run. Solution composition was set by mineral solubilities, breakdown of dolomite, and complex ion formation. Elements found in Carlin-type gold deposits were solubilized.

SOLUTION COMPOSITION IN PPM

	3/1	10/1		3/1	10/1
SiO_2	1021	987	Fe	4.0	0.18
K	800	85	Hg	0.036	0.032
Ca	126	70	S	0.013	<0.05
Ba	8.3	2.0	Tl	0.054	<0.04
As	4.6	0.15	H_2S	6	17
As	0.043	0.010	CO_2	20000	2000
B	3.0	0.25	pH	5.4	5.3

METALLIFEROUS DEPOSITS OF THE TROODEN OPHIOLITE: A GENETIC MODEL

D. R. Jamieson
W. E. Seyfried (both at: Dept. of Geology and Geophysics, Univ. of Minnesota, Minneapolis, MN, 55455)
(Sponsor: M. Mazares)

Seawater-basalt interaction at elevated temperatures and pressures, under seawater dominated conditions, appears to be responsible for the metalliferous deposits within the Troodens ophiolite. Experimental studies show that a fluid significantly enriched in Fe, Mn, Zn, Cu, H_2S (total dissolved H_2S) and $LiCl$ can be derived by reaction of seawater with basalt at temperatures $\geq 300^\circ C$ and at effectively seawater/rock ratios ≤ 50 . At Troodens, a fluid with these characteristics ascending along fault zones and subsequently debouching into near water can account for the stratigraphy, textures and chemistry of the massive sulfides of the Lower Pillow lavas.

The Fe-Mn oxide deposits (umbels) which characterize metalliferous within the Upper Pillow lavas are strikingly similar in chemistry to the heavy metal-rich sediments presently accumulating on the East Pacific Rise. It appears that these deposits resulted from seawater-basalt reaction, also at high seawater/rock ratios, but at temperatures substantially less than 300°C. Experiments reveal that appreciable Fe and Mn can be solubilized under these conditions. Furthermore, the altered seawater lacks H_2S , accounting for the absence of pyrite and the oxidized nature of the umbel deposits.

Airborne Sampling of Eruption Clouds of Explosive Volcanoes
Crystal Room (HI), Wednesday 1330h
R. D. Cadle (National Center for Atmospheric Research), and
W. I. Rose, Jr. (Dept. of Geology and Geological Engineering, Michigan Technological University), Presiding

V 73 INVITED PAPER

ACTIVITY OF CENTRAL MEXICAN VOLCANOS, FEBRUARY 1978

W. I. Rose, Jr. (National Center for Atmospheric Research, Boulder, CO 80502; pres. address: Michigan Technological University, Houghton, MI 49931)

Three volcanoes, two basaltic (Fuego and Parí) and one dacitic (San Jacinto), were in almost continuous activity during February 1978, the time of our volcano cloud sampling. Almost continuously active since 1963, Fuego has alternated between mild Strombolian activity sometimes accom-

guided by lava flows and explosive volcanic activity. During our sampling, Pacaya was in a state of intense vapor emission which began in December 1977 and continued at least through May 1978. Little or no ash was being erupted, and no lava flow activity was occurring either. When vapor emission abated during our sampling flights, some could be directly observed through cracks within the Mummy crater. Pacaya has departed from its 50-year pattern of short-lived, frequent, violent paroxysmal eruptions. Beginning in September 1977 and continuing until at least June 1979, Pacaya has been in constant low-level paroxysmal activity. In February 1978, lava flows, the first since at least 1912 at Pacaya, were flowing down the SW flank of the cone. Larger lava flows were seen in the E flanks in June. Mild volcanic activity producing substantial amounts of ash was interspersed with vaporous, ash-poor plumes in February. Both types of eruption clouds were sampled. Santiaguito is a Peléan dome, which has been continuously erupting since 1922. Since April 1975 the volcano has been producing several paroxysmal eruptions each day, some reaching heights of 5 km. During February this activity continued to produce large, ash-rich eruption clouds. Continual, relatively low level activity at ever-changing subsets of Central America volcanoes allow planned missions to sample explosive volcanic clouds at small (<5000 m) volcanoes in good (dry season) weather conditions.

NIHAR is sponsored by the National Science Foundation.

V-74 INVITED PAPER

SULFUR AND HALOGEN CONSTITUENTS OF VOLCANIC ERUPTION CLOUDS

A. L. Lazrus
R. J. Huebert
R. D. Cadle (all at: National Center for Atmospheric Research, Boulder, CO 80507)
M. L. Rose, Jr. (Michigan Technological University, Houghton, MI 49931)

Volcanic plumes in Guatemala and Alaska were sampled for SO₂, HCl and HF vapors as well as SO₂, Cl⁻ and F⁻ in particles. The molar ratios for SO₂/HCl varied from 1.2 to 2.5, and that of HCl to HF from 5 to 21. Selective removal of HCl and HF with respect to SO₂ as a function of distance from the crater was not observed. The average percentages of sulfur, chlorine and fluorine in the particle phase are respectively 2.5, 18 and 52.

The amount of sulfate present in the northern hemisphere stratosphere in Spring 1975 resulting from the Fuego eruption in Fall, 1973, has been estimated from depth maps of sulfate concentration obtained by means of WRSII aircraft and balloons.

V-75 INVITED PAPER

AIRBORNE CORRELATION SPECTROMETER MEASUREMENTS OF SO₂ IN ERUPTION CLOUDS FROM GUATEMALAN VOLCANOS

Richard F. Stroh
G. Bratton (both at: Dept. of Earth Sciences, Dartmouth Coll., Hanover, NH 03755)

Measurements of SO₂ emitted during mild eruptions of the Guatemalan volcanoes Fuego and Santiaguito emitted in a strong vapor cloud at Pacaya were made with an airborne remote sensing correlation spectrometer. Emission of 100 to 1500 metric tons per day of SO₂ is comparable with data from ground-based measurements made at other times and at other volcanoes elsewhere. The airborne mode eliminated the necessity of roads being positioned appropriately relative to the plume; and allows many traverses to be made beneath the plume in a short period of time. These traverses may be at any desired distance below the plume or downwind from the crater. Thus one can investigate the change in SO₂ in the plume downwind as well as the instrument response at various distances beneath the horizontal plume due to vertical distribution of the gas and to atmospheric attenuation. Measurements indicate attenuation loss of at least 20% in the signal from a plume where it is 1.8 km above the aircraft and a marked drop of up to

40% in SO₂ content downwind at distances of up to 25 km from the volcanic crater. Use of the spectrometer in an aircraft requires appropriate navigational aids and an exit port for the telescope with no overhead obstructions.

V-76 INVITED PAPER

GAS AND R ISOTOPIC ANALYSES OF VOLCANIC ERUPTION CLOUDS IN GUATEMALA

M. L. Rose, Jr.
R. D. Cadle
L. E. Heidt
R. J. Huebert
A. Lazrus (all at: National Center for Atmospheric Research, Boulder, CO 80507; pre-address (Rose): Michigan Technological University, Houghton, MI 49931)
I. Friedman (U. S. Geological Survey, Denver CO 80225)

Gas samples were collected by aircraft entering volcanic eruption clouds of three Guatemalan volcanoes. Gas chromatographic analyses show higher H₂ and S₂ contents in ash eruption clouds and lower H₂ and S₂ gases in vaporous gas plumes. R isotopic data demonstrate lighter isotopic distribution in water vapor of ash eruption clouds than in vaporous gas plumes. Most of the H₂O in the vaporous plumes is probably meteoric. The data are the first direct gas analyses of explosive eruption clouds, and demonstrate that, in spite of atmospheric advection, useful compositional information on eruptive gases can be obtained using aircraft.

V-77 INVITED PAPER

PARTICLE SIZE DISTRIBUTION AND MORPHOLOGY OF ASH IN THE FUEGO AND SANTIAGUITO PLUMES

Stephen Seif (Dept. of Earth Sciences, Dartmouth College, Hanover, NH 03755)

Airborne collection of pyroclastic particulates in the plume of Fuego and Santiaguito Volcanoes, Guatemala was conducted in February 1978. Particles were collected on both Fluoropore filters and on a quartz crystal microbalance (QCM) cascade impactor between 12 and 15,000 ft. above sea level and at various distances downwind. SEM examination of particles shows size range, particle type and morphology. Solid particles in the plume are juvenile scoria, crystal fragments and comminuted non-juvenile lithic material. Sizes range from 10m to 0.05µm and the progressive downwind decrease of the coarse fragment content can be documented. This is compared to plume dynamics obtained from movie film of the explosions which produced the ash contained in the plume. Initial plume velocities of 10 m/s, which decelerate dramatically to a few meters per second before being blown downwind, supported particles <25 µm up to distances of 15 km from Fuego Volcano with bulk concentrations of several thousand µg/m³. Data will also be presented on the relative concentration of the various particle types and the total grain size distribution in an eruption plume produced by mild volcanic explosions.

V-78 INVITED PAPER

SIZE DISTRIBUTION, MORPHOLOGY AND ELEMENTAL COMPOSITION OF FINE PARTICLES IN VOLCANIC PLUMES

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R. L. Chum (Brunswick Corp., Costa Mesa, CA 92626)
(Sponsor: R. D. Cadle)

Fine particles (from about 50 to 0.05 microns in diameter) in the eruption plumes from two active volcanoes, Fuego and Santiaguito, were sampled in situ to determine mass concentration and size distribution, with elemental composition and morphology determined from post sampling analysis. The samples were taken during an aircraft sampling mission in Guatemala in February and March 1978. The particles were

collected with a 10 stage cascade impactor which has pleated electrically conductive collectors that produce, in real time, electrical signals corresponding to the mass of material deposited on the collector surfaces. The samples were photographed and analyzed by a scanning electron microscope equipped with an energy dispersive x-ray analysis attachment to determine elemental composition. The particles appeared to be divided among two morphological groups, large agglomerates in the larger size fractions and less agglomerated particles in the small size fractions, giving the overall size distribution a bimodal character. Mass densities of the particles were estimated from their geometric sizes as seen in the SEM. The large agglomerates were estimated to have mass densities less than 1.0 gm/cm³ while the spherules have mass densities of about 2.0 gm/cm³. Supporting data from another sensor on board the aircraft indicate that most of the particles are liquid-crystalline, presumably HCl and H₂SO₄. Energy dispersive x-ray analysis reveals significant amounts of Al, Si, Ca and Fe with lesser amounts of Cl, K and Ti in the large agglomerates and Al, Si, Fe and Ti in the submicron groups.

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VOLCANIC EXPLOSION PLUMES: DENSITY, TEMPERATURE AND PARTICLE CONTENT ESTIMATES FROM PLUME MOTIONS

L. Wilson (Environmental Science Dept., Univ. of Lancaster, Lancaster LA1 4YW, U.K.)
S. Seif (Dept. of Earth Sciences, Dartmouth College, Hanover, N. H. 03755)

Analyses are reported of 2 eruption clouds from Fuego, filmed at one frame per second on February 27, 1978, as part of NIHAR's Central American Volcano Plume Sampling Experiment. The movement of a cloud between frames gives its velocity. The velocity/time curve can be differentiated to find the acceleration and hence the total force acting on the cloud. This force consists of 2 parts, air drag (most important at high speeds early in the motion) and buoyancy (most important late in the motion when the cloud is convecting slowly). Equations of motion were derived for 2 common cloud shapes, spheres and vertical cylinders, and cloud densities were calculated by fitting the equations to the observed motions. A simplified analysis of the heat budget of a cloud permits an estimate of cloud temperature and particle weight fraction to be made from the density. Clouds generally reached temperatures within 10% of that of the surrounding air within 10 seconds of formation. Dense particle weight fractions were less than 2% by this time, and cloud rise velocities less than 5 m/s. In 4 cases it was possible to estimate the maximum size of dense particles supported by the cloud motion. Values found were 315, 200, 140, and 560 microns.

V-79 INVITED PAPER

TRACE METALS IN VOLCANIC ERUPTION CLOUDS

D. B. Seif
R. A. Zlotoski (both at U.S. Geological Survey, Denver, Co. 80225)
(Sponsor: C. W. Huebert)

In February and March of 1978 filter samplers mounted on an aircraft were used to collect the aerosol fraction of the eruption clouds of three active Guatemalan volcanoes (Fuego, Pacaya and Santiaguito). The filter sampler consisted of three filters in series. The first was a Fluoropore filter with a nominal pore size of 0.5 microns for removing particulates from the eruption cloud. The next two filters were Whatman filters treated with tetradecyl ammonium hydroxide to preferentially retain acidic volatiles contained in the cloud. The mass of air sampled by the filters ranged from 15 to 6.6 kg, for each volcano sample were collected at increasing distances from the vent. After collection of the samples, each filter was extracted with 60 ml of water. Solids were filtered and analyzed for 14 metals by inductively coupled plasma-optical emission spectroscopy. Fluoride and chloride were analyzed by specific ion electrode.

The elements found in significant concentrations in the Fluoropore extracts are as follows (in decreasing order of concentration): Al, Ca, Fe, Mg, Cl, Na, K, Pb, Zn, V, Pb, Cu, Sr and Cd. These elements represent components of water-soluble substances derived from interaction of particulates and acidic gases of the eruption cloud. Elements found in the extracts of the

treated Whatman filters are the decreasing order of concentration: Cl, Cu, Br, Pb, Sr, Fe, Ba, and Mg. It is concluded that volatile transport plays a role in the distribution of these elements within a volcanic eruption cloud.

1. INVITED PAPER

IMPLICATIONS OF STUDIES OF GEOTERMAL VOLCANOS WITH REGARD TO STRATOSPHERIC TRACE CONSTITUENTS

R. D. Catlett
R. L. Borchert

A. L. Farnes (Editor: National Center for Atmospheric Research, Boulder, CO 80507)
W. L. Rose (Editor: Technological University, Brighton, ME 04001)

Observations made during February, 1978, of the physical and chemical properties of the eruption clouds from three Caribbean volcanoes, namely Fuego, Irazu, and Santiquito, are analyzed from the standpoint of the trace gas and particle composition of the stratosphere. Since most of the sulfur was in the form of SO_2 , the H_2SO_4 droplets resulting from major explosive eruptions most likely result from the reaction of SO_2 with OH , at the same time depleting the stratosphere of OH . The volume concentration ratio $[\text{SO}_2]/[\text{HCl}]$ always somewhat exceeded unity. Probably rain accompanying huge explosive eruptions would remove HCl from the stratosphere. The lowest volume concentration ratio $[\text{H}_2\text{SO}_4]/[\text{HCl}]$ was 2.9×10^3 from which we deduce that perhaps as much as 10% of the HCl in the stratosphere is volatile. The amount of time HCl remaining in the stratosphere for long periods of time may depend on the crystallinity of the magma.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation.

2. INVITED PAPER

THE CHEMISTRY OF ATMOSPHERIC PARTICULATE MATERIAL EMITTED BY VOLCANOS

W. H. Zoller (University of Maryland, Department of Chemistry, College Park, Maryland 20742)
W. C. Cunningham (University of Maryland, Department of Chemistry, College Park, Maryland 20742)
E. A. Lopez (Battelle-Northwest Laboratories, Richland, WA 99152)

Samples of airborne particulate material have been collected from Mt. Erebus in Antarctica using the National Science Foundation DC-130 Hercules aircraft. These samples have been analyzed for their trace element composition by Neutron Activation Analysis. Additional samples of condensed gaseous material were collected on the summit of Mt. Erebus for comparison with the plume analyses. The results of the analyses of these samples are compared with the results of Hickey in Iceland and Augustine in Alaska. The data on volcanic emission points to the release of volatile trace metals in high abundances relative to the matrix ash. The elements are the same ones observed in anomalously high concentrations in remote areas of the world. The implications of this trace element fraction will be discussed.

3. INVITED PAPER

THE EFFECT OF VOLCANIC EMISSIONS ON THE GASEOUS ATMOSPHERIC CHEMISTRY OF THE VOLCANO

C. Corns, W. L. Farnes, R. D. Catlett, R. L. Borchert, R. L. Borchert, and R. L. Borchert
*These authors are at the National Center for Atmospheric Research, Boulder, CO 80507
†These authors are at the Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125

From an interpretive review of previous work and current observations, a volcanic input rate of 10^4 to 10^5 moles SO_2 to the global atmosphere has been estimated by three independent methods.

This SO_2 flux can be used to calculate the volcanic contribution of Hg and Pb to the atmosphere. Theoretically, gas at 100°C from Kiln Volcano in Hawaii contained $48 \mu\text{g Hg/m}^3$ and $275 \mu\text{g Pb/m}^3$ on a water-free basis, and Hg/S weight ratio of 5.1×10^{-3} and Pb/S of 3.1×10^{-3} . The gas contained 60, 40, 30, and 20% of which was meteoric, $15, 50, 25, 10$ and 25% of which was volcanic. Volcanic emission of Hg to the atmosphere is estimated to be 3 to 9 ton/yr , which is negligible compared to the $9,000$ tons H_2SO_4 emitted to be released from both anthropogenic and other natural sources. This agrees within an order of magnitude with the potential volcanic emission rate of Hg calculated from the average Hg content of volcanic rocks and the sub-aerial lava production rates. Volcanic emission of Pb to the atmosphere is estimated to be 3×10^4 ton/yr, which is not significant compared to a world input of 10^6 tons Pb/yr of "fine-sized, Pb-rich particles from automobile exhausts." It is recognized that the extrapolation of the metal/S ratios from the Kiln Volcano fumarolic gas as representative of eruptive gases from volcanoes throughout the world involves large uncertainties. However, increase of Hg/S or Pb/S in volcanic gases by 2-3 orders of magnitude would still permit the conclusion that the volcanic source of Hg and Pb in the atmosphere is not significant compared to anthropogenic and natural sources for Hg and anthropogenic sources for Pb.

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RECONSTRUCTION OF THE 1970 VOLCANIC GAS ANALYSES FROM MOUNT ETNA, ITALY*

T. M. Gerlach (Florida Laboratories, Albuquerque, New Mexico 87105)

The analyses of volcanic gases collected during the 1970 eruption of alkali basaltic lava at Mount Etna (Huntington, 1973) are among the most reduced volcanic gases ever reported (20 to 50% H_2 , 1 to 3% CO and 1 to 10% CH_4). They show gross chemical disequilibrium at all temperatures as a result of extensive oxygenation and limited sulfur-loss from reactions with metal collection devices. Thermodynamic calculations have been used to restore oxygen lost from each sample. The O_2 and H_2 partition of the restored analyses are in good agreement with those measured in the gas sampling after the time of collection (Oato and Moore, 1973) and with those reported for alkali basalts from Tristan da Cunha Island. The corrected concentrations of H_2 are low (0.4%) and offer little support for Huntington's suggestion that violent volcanic explosions may be related to rapid combustion of H_2 -rich gases derived from erupting magmas. Unlike the original analyses, the restored analyses show uniform and steady composition at each collection site. All corrected analyses fit recently proposed composition limits for basaltic volcanic gases (Gerlach and Hordell, 1975). H_2 is the dominant species, but the most interesting feature of the corrected analyses is their high concentrations of SO_2 (15 to 65%) and CO (15 to 19%). These characteristics are consistent with recent petrologic models for the origin of alkali basalts.

*This work supported by the United States Department of Energy.

Trace Element Migration by Fluid Flow 1

Cathedral Hill A (JT), Thursday 0820h

M. G. Seitz (Argonne National Laboratory), and
D. G. Brookins (Department of Geology, University of New Mexico), Presiding

4. INVITED PAPER

THE TRANSPORT OF TRACE ELEMENTS FROM AN INJECTION WELL

Randy L. Russell (U.S. Geological Survey, Denver, Colorado 80225)

Artificial recharge often involves injection of water different in quality from the native ground water into aquifers. Because of this, the U.S. Geological Survey Artificial Recharge Research

Project is currently studying the transport of environmentally and geochemically significant trace elements in the Ogallala aquifer in Texas. Elements under investigation are H, Cu, B, Cl, Br, F, and I which either occur naturally in significant concentrations in this region, or behave in a manner similar to the elements that might be in the injection water. In studies conducted to date, both ground water and surface water have been injected into the aquifer, and the resultant chemical changes were monitored at sampling points located radially from the well. These experiments were designed to (1) determine the radial and vertical variation in the hydrodynamic dispersion coefficient, (2) compare the accuracy of monitoring the breakthrough of a tracer in vertically separated point samplers with integrated samples from an observation well screened throughout the aquifer, and (3) observe the chemical reactions that occur as the fluid migrates from the well.

The halides, Cl, Br, and I, have been used by other workers as tracers to interpret hydrologic flow regimes. This study indicated that all halides except Cl do sorb on aquifer materials to some extent. Consequently, these halides make less than ideal tracers in defining the flow systems in the Ogallala aquifer. Both H and F were retained in the aquifer through sorption; in addition fluoride may also be retained by precipitation of fluoride as fluorite (CaF_2). Copper and uranium were transported or retained by complexation, adsorption, and precipitation, which are the same mechanisms that affect most trace metals in an alkaline and oxidizing ground water.

5. INVITED PAPER

THE SIMULATION OF SOLUTE AND HEAT TRANSPORT TO EVALUATE AQUIFER PARAMETERS

E. C. Lippala (U.S. Geological Survey, Denver, Colorado 80225)

A model that simulates the radial transport of chemical compounds and heat, which are used as tracers in injection well tests, has been developed and used to (1) determine aquifer parameters such as longitudinal dispersivity, effective porosity, and thermal conductivity and (2) to evaluate the retention of chemical tracers on aquifer materials. The model consists of an implicit finite-difference solution to the dispersion-convection equation in radial coordinates, coupled with an analytical solution to the radial ground-water flow equation. The analytical solution accounts for velocity variations due to changing injection rates. In field situations where the aquifer was layered, reasonable success was achieved by applying the model to each layer, apportioning the flow into each layer based upon flow-meter surveys during injection.

The model has been used to evaluate aquifer parameters in single-well injection tests in a sand and gravel aquifer in central Nebraska, and in the Ogallala aquifer in southwest Texas. Tracers used were heat, bromide, iodide, boron, fluoride, and fluorocarbon.

6. INVITED PAPER

URANIUM MOVEMENT IN OGALLALA AQUIFER, WEST TEXAS AND EASTERN NEW MEXICO

C. G. Reeves, Jr. (Dept. of Geosciences, Texas Tech University, Lubbock, Texas 79409)
(Sponsor: Stanley E. Gellett)

Regional analysis of uranium in ground water from the Ogallala aquifer reveals an increasing content from northwest to southeast, except for sporadic local anomalous areas. The area of greatest regional concentration extends from the Lubbock area south and west to the Big Spring-Millardville area. In most of eastern New Mexico the uranium content of Ogallala ground water ranges between 2 and 3 ppb, increasing to the 3 to 4 ppb range just east of the state line. Content increases rapidly until a regionally mappable area having uranium contents >12 ppb occurs from Lubbock south into Garza County. Sporadic localities do exist where the uranium concentration in the Ogallala ground water exceeds 50 ppb. The general trend of uranium concentration in ground water southwest of Lubbock coincides with the regional distribution of other elements in the ground water. For example, sodium, chloride, fluoride and nitrate as well as total dissolved solids exhibit high regional concentrations southwest of Lubbock in an area characterized by a thin Ogallala section over Cretaceous topographic highs, ancient lake basins

Recent publications under NSG 5145:

In Press-

- Self, S., Wilson, L. and Nairn, I.A., 1979, Vulcanian eruption mechanisms, *Nature* (London); (proofs attached to this report).
- Self, S. and Sparks, R.S.J., 1979a, Characteristics of pyroclastic deposits formed by the interaction of silicic magma and water, *Bull. Volcanol.*, 41-3.
- Self, S. and Sparks, R.S.J., 1979b, Discussion of "The oldest marine carbonate ooids reinterpreted as volcanic accretionary lapilli, Onverwacht Group, So. Africa, by D.R. Lowe and G.P. Knauth. *J. Sed. Petrol.* (June).
- Kienle, J., Self, S., Kyle, P.R. and Motyka, R., 1979, Ukinrek Maars, Alaska: I. General Geology and Petrology. *J. Volcanol. Geothermal. Res.*
- Self, S., Huot, J.P. and Kienle, J., 1979, Ukinrek Maars, Alaska: II. Mechanisms and deposits of the 1977 eruption. *J. Volcanol. Geothermal. Res.*

Articles in preparation:

- Wilson, L. and Self, S. Volcanic explosion plumes: density, temperature and particle content estimates from plume motion. To be submitted to *Geophys. Res. Letts.*
- Walker, G.P.L., Self, S. and Frogitt, P. The ground layer of the Taupo Ignimbrite: a striking example of sedimentation from a pyroclastic flow. To be submitted to *Geology*.
- Rampino, M.R., Self, S. and Fairbridge, R.W. Can climate change cause volcanic eruptions? To be submitted to *Science*.
- Wright, J.V., Smith, A.L. and Self, S. A proposed classification of pyroclastic rocks; to be submitted to *Geology*.
- Newhall, C.G. and Self, S. A new volcanic eruption list: applications to the study of volcanic perturbation of global climate; to be submitted to *J. Geophys. Res.*

Abstracts published:

- 1978 Self, S., Kienle, J. and Huot, J-P, Mechanisms and deposits of the 1977 Ukinrek maar-forming eruption, Alaska Peninsular; Geol. Soc. Am. abstracts with programs, 10. p. 489.
- 1978 Rose, W.I., Jr., with S. Self and ten others, 1978 volcanic plume sampling project; Geol. Soc. Am. abstracts with programs, 10. p. 480-481.
- 1978 Self, S., Particle Size Distribution and Morphology of Ash in the Fuego and Santiaguito Plumes. Trans. Am. Geophys. Union (EOS), 59, p. 1222.
- 1978 Wilson, L., Self, S., Volcanic Explosion Plumes: Density, Temperature and Particle Content Estimates from Plume Motions. Trans. Am. Geophys. Union (EOS), 59, p. 1222.